Direct Calibration of Field Response Function in LArTPC

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DUNE Collaboration Meeting

Signal Processing in LArTPC

- Field response and electronics response are essential for LArTPC detector signal processing
- Electronics response is calibrated with dedicated pulser data
- We propose a direct calibration of field response function

Number of Ionized electrons

↓ *Field Response*

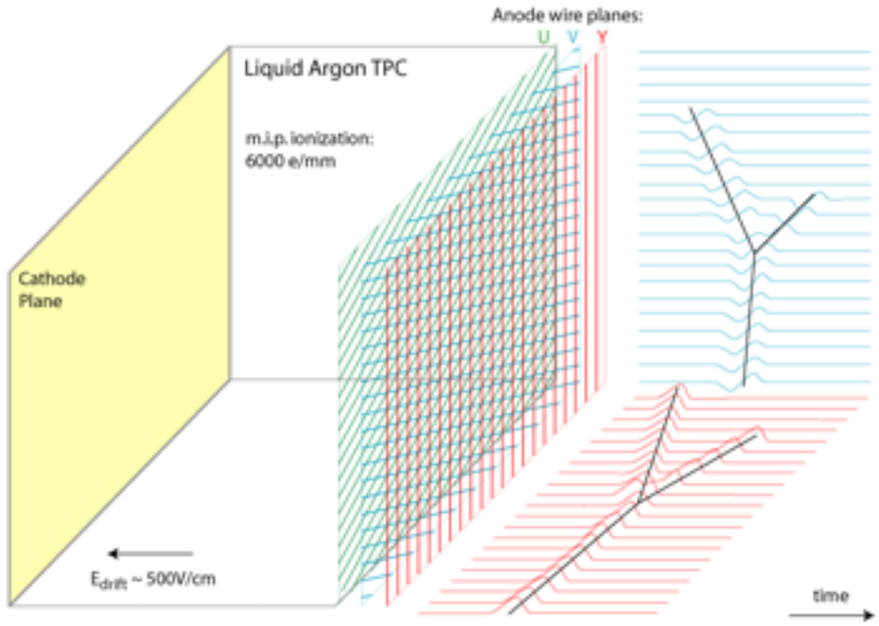
Signal on Wire Plane

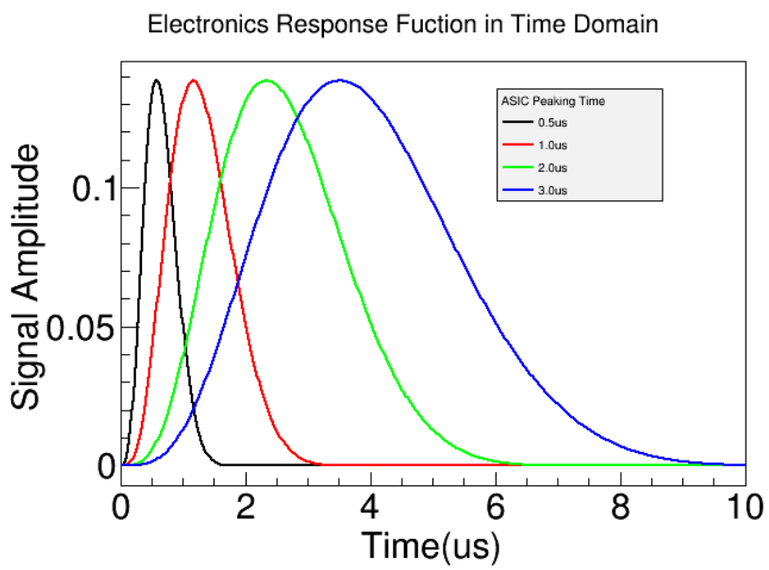
↓ *Electronics Response*

Signal to be digitized by ADC

↓ *Deconvolution*

Number of Ionized electrons



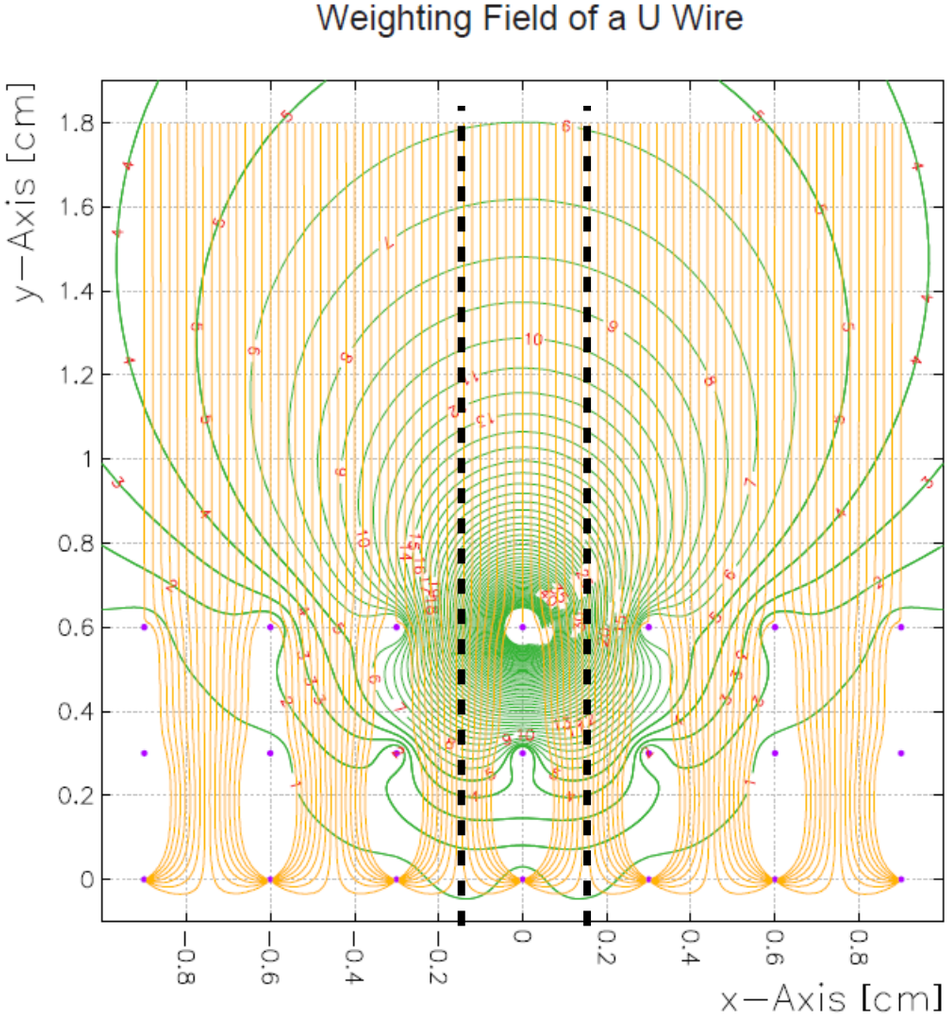


Physics behind Field Response Function

- The induction current is described by Shockley-Ramo theorem:

$$i = -q \cdot E_w \cdot v$$

q-charge; E_w-weighting field; *v*-velocity



- $\boldsymbol{E_w}$ is the electric field for electrode with induction current at unit potential; and all other electrode at ground

- $\boldsymbol{E_w}$ extends beyond the boundary of wires (±half pitch), i.e., electrons pass through the adjacent wires can also produce induction current on the wire of interest

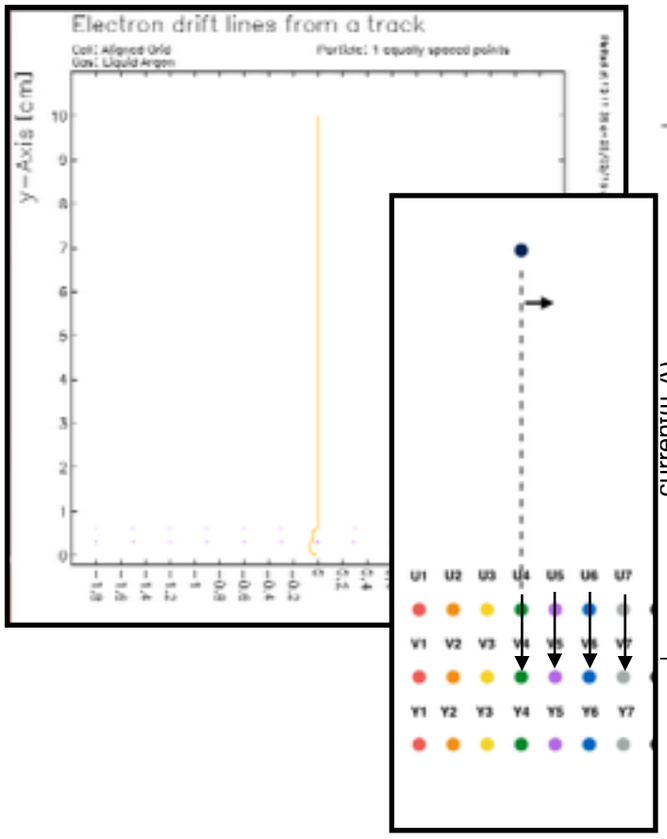
- ***v*** depends on electric field + location…..

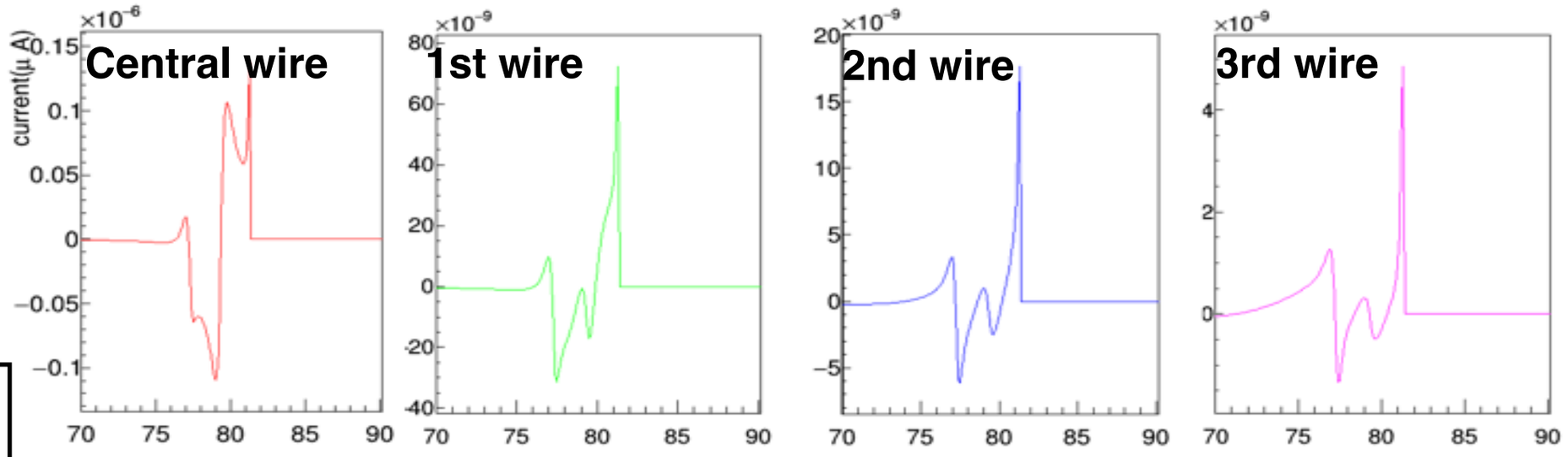
- Induction current strongly depends on the local charge distribution

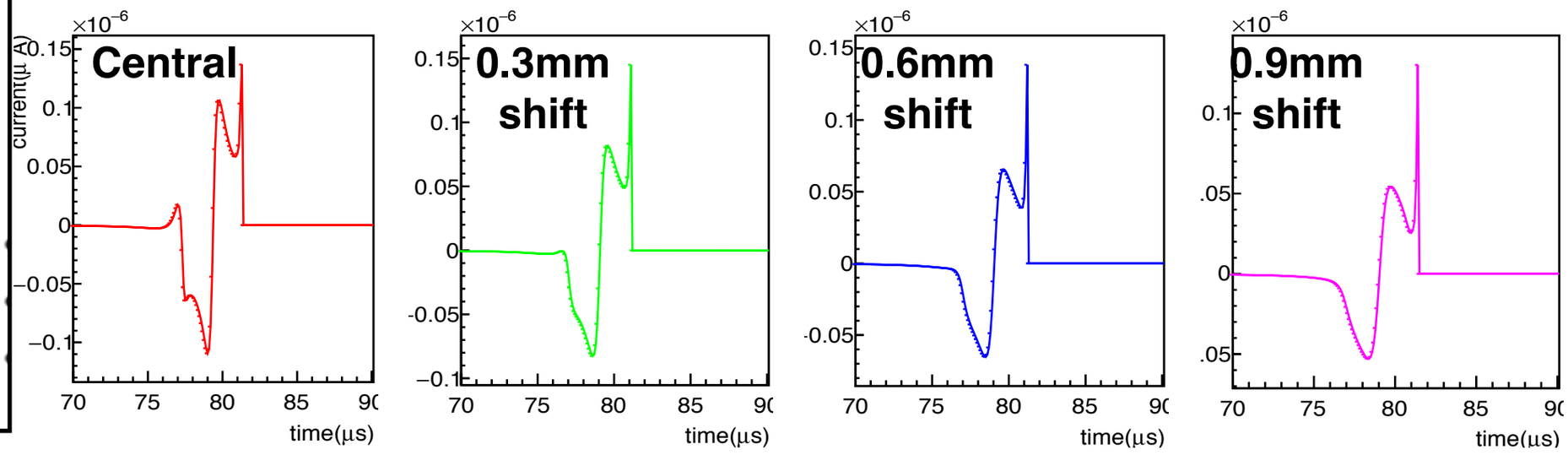
Prediction of Field Response Function

- Current prediction of field response function is based on Garfield-2D

V Plane







- 2D results doesn't agree with data (e.g. time offset). 3D is definitely needed

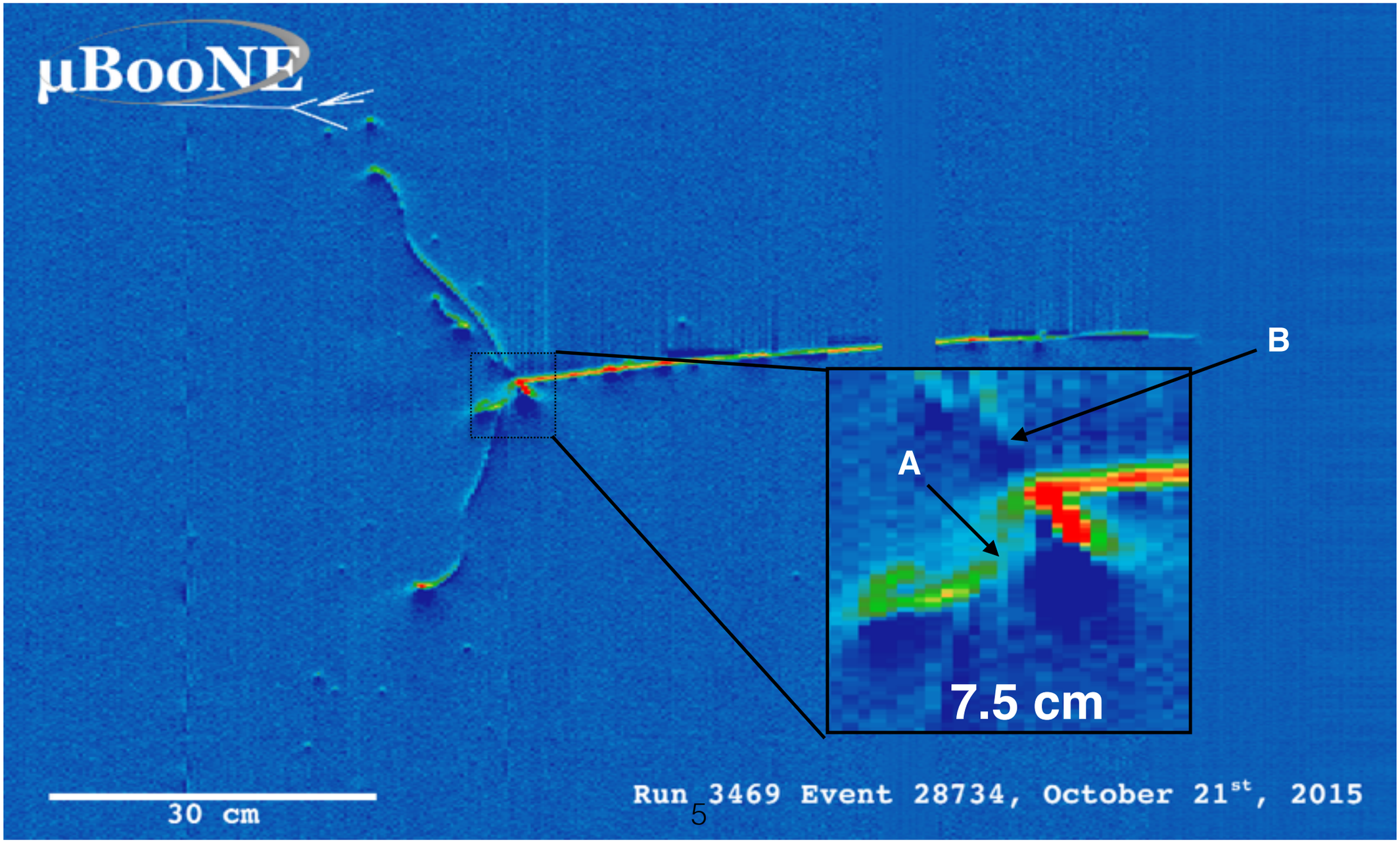
- Due to various technical difficulties, there is no realistic field response function in 3D available

Events from MicroBooNE

- Variations on TPC signal shape are typically signifiant at the neutrino interaction vertex. (tracks are dense within several neighboring wires on induction plane)

- Reconstructing tracks close vertex correctly is critical for e/γ separation.

- Using an averaged field response function will lead to artificial effects on the image



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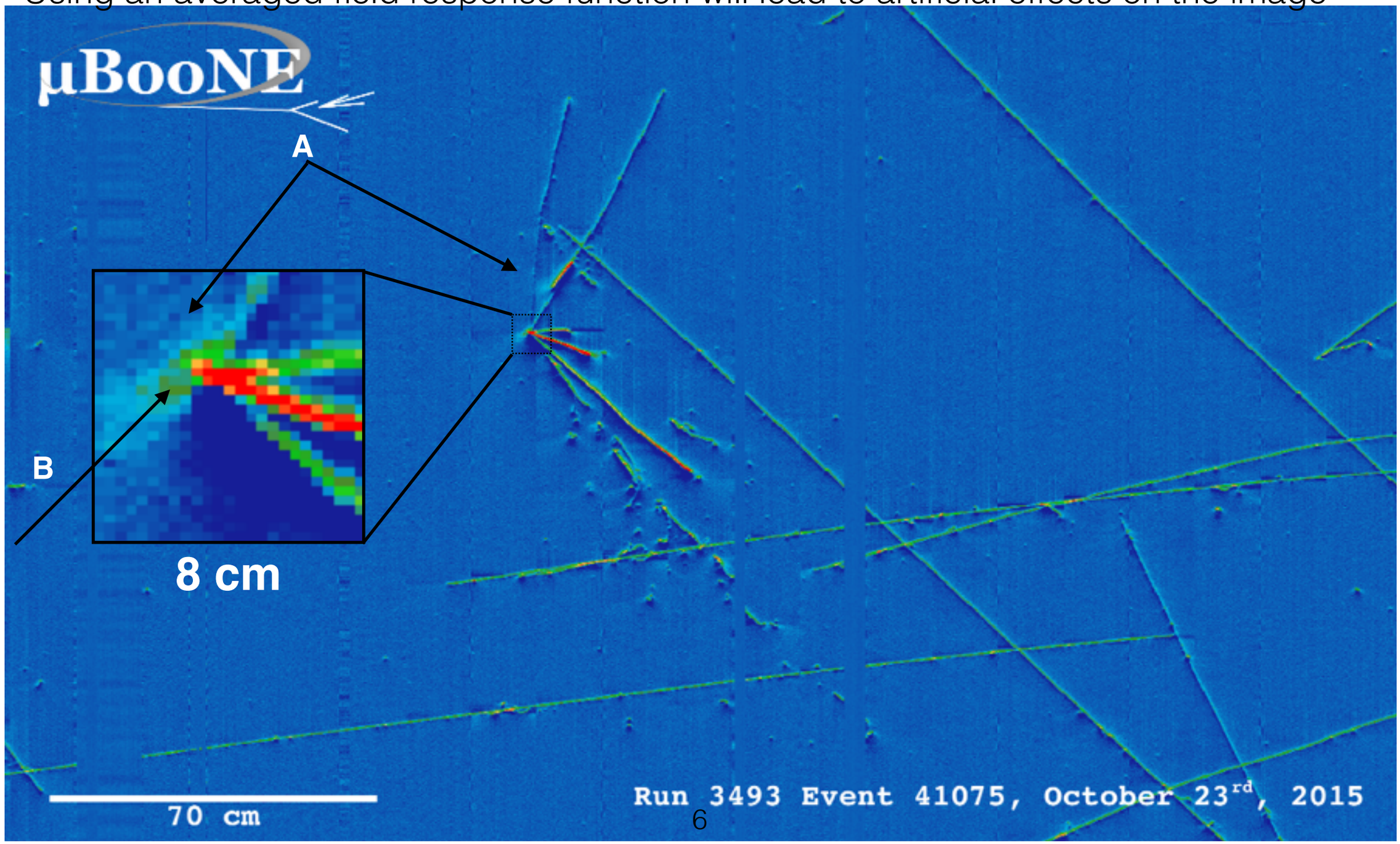


Progress in LArTPC signal processing

- Proper recovery of the number of ionized electrons is crucial

- MicroBooNE has worked out a procedure to recover number of ionized electrons (See X.Qian's talks at reco session) : *2D deconvolution* + *ROI* + *Adaptive base*. One missing piece is the field response function calibration

Measured Signal Field Response Signal

$$\begin{pmatrix} M_1(\omega) \\ M_2(\omega) \\ \vdots \\ M_{n-1}(\omega) \\ M_n(\omega) \end{pmatrix} = \begin{pmatrix} R_0(\omega) & R_1(\omega) & \dots & R_{n-1}(\omega) & R_n(\omega) \\ R_1(\omega) & R_0(\omega) & \dots & R_{n-2}(\omega) & R_{n-1}(\omega) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R_{n-1}(\omega) & R_{n-2}(\omega) & \dots & R_0(\omega) & R_1(\omega) \\ R_n(\omega) & R_{n-1}(\omega) & \dots & R_1(\omega) & R_0(\omega) \end{pmatrix} \cdot \begin{pmatrix} S_1(\omega) \\ S_2(\omega) \\ \vdots \\ S_{n-1}(\omega) \\ S_n(\omega) \end{pmatrix}$$

Scheme of 2D-deconvolution

Requirements of a Field Response Calibration System

- A bright point-like electron source is favored
- The multiple known source positions are crucial
- The electron spot is close to the wire plane to limit diffusions
- Averaging is needed to minimize electronics noises->trigger is desired
- Distortion by digitization must be minimized
- Negligible influence on the drift field

- *This talk, we propose a scheme of field response calibration system with photocathode driven by pulsed laser*

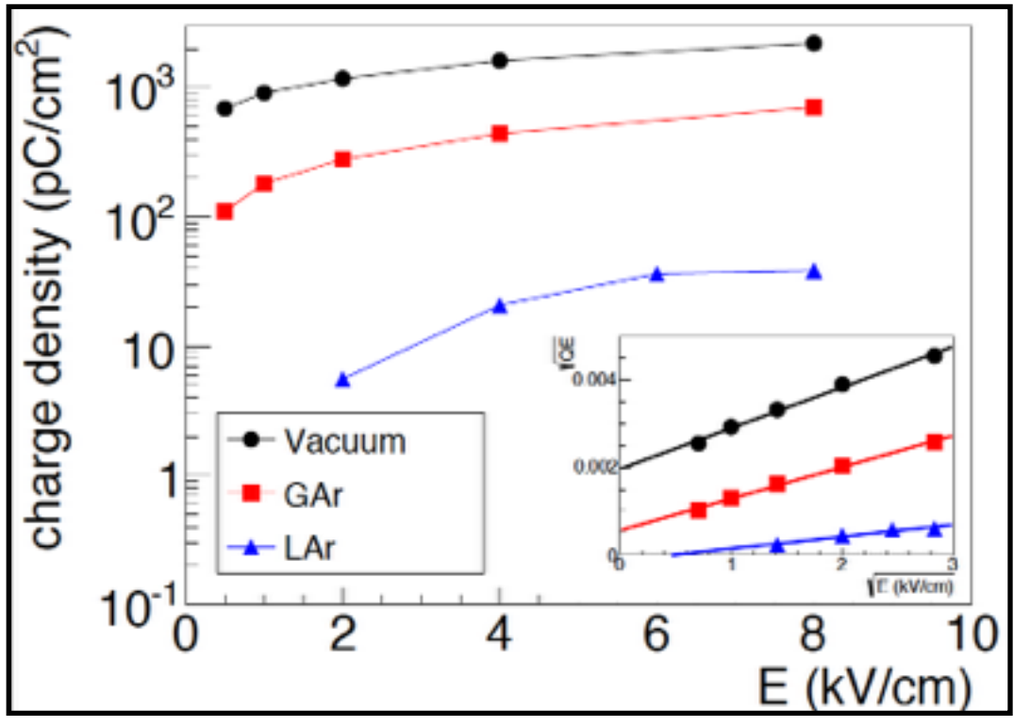
Some Quantitative Estimations

- Assuming similar front-end noise as MicroBooNE, the ENC noise with 7.29m wire length is ~500 electrons

- We have found Au photocathode driven with pulser laser can produce ~10^5 electron in LAr which is sufficient

- With focus lens/fiber, the laser spot size can be reduced to ~100 um, which is enough for ~3-5 mm wire spacing

Au PhotoCahtode



- *Y. Li et al. NIM A 816 (2016) 160–170*
- *Y. Li et al. arXiv:1602.01884*

Basic Strategy

- Local test stand with a TPC + adjustable wire pitch + gold photocathode + laser

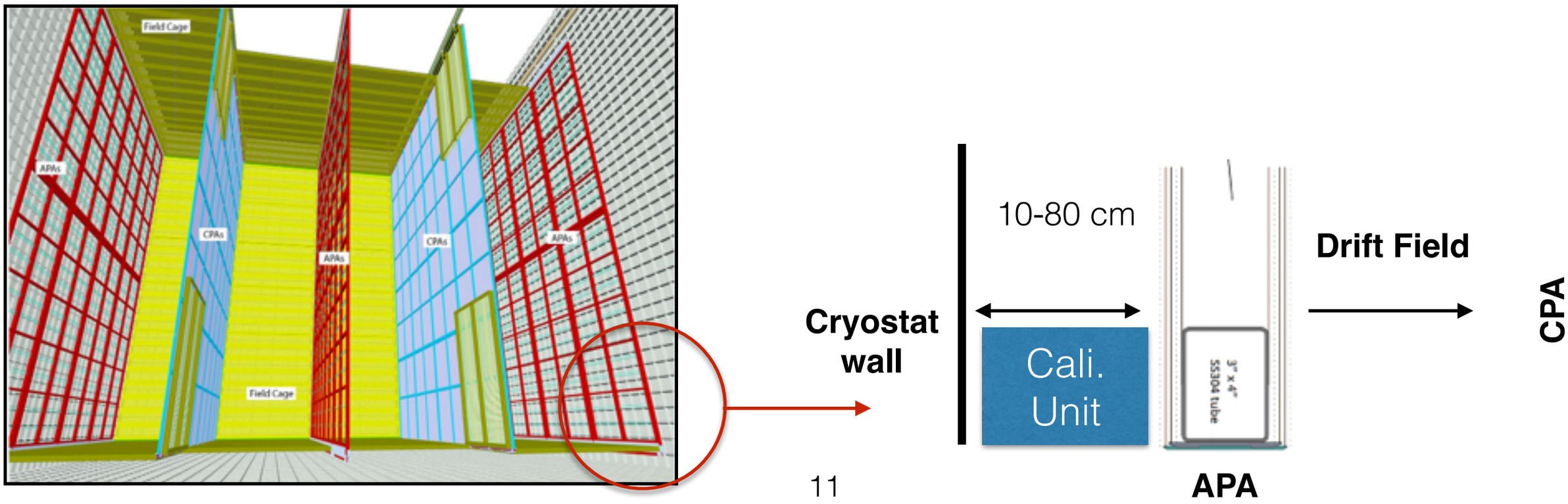
- Advantages: Easy to debug and can satisfy needs by multiple experiments

- At the same time, do we need a in-situ calibration device in large LArTPC ?

- Should we prepare such a device for DUNE ?

Concept

- The APA plane facing towards the cryostat wall is not used at this moment is ideal location to install the unit
- Uniform electric field can be generated by a short field cage.
- A bias HV of only <10 kV is enough to maintain the drift field of 0.5 kV/cm



Conclusion

1. A direct calibration of field response function is important to process the LArTPC signal

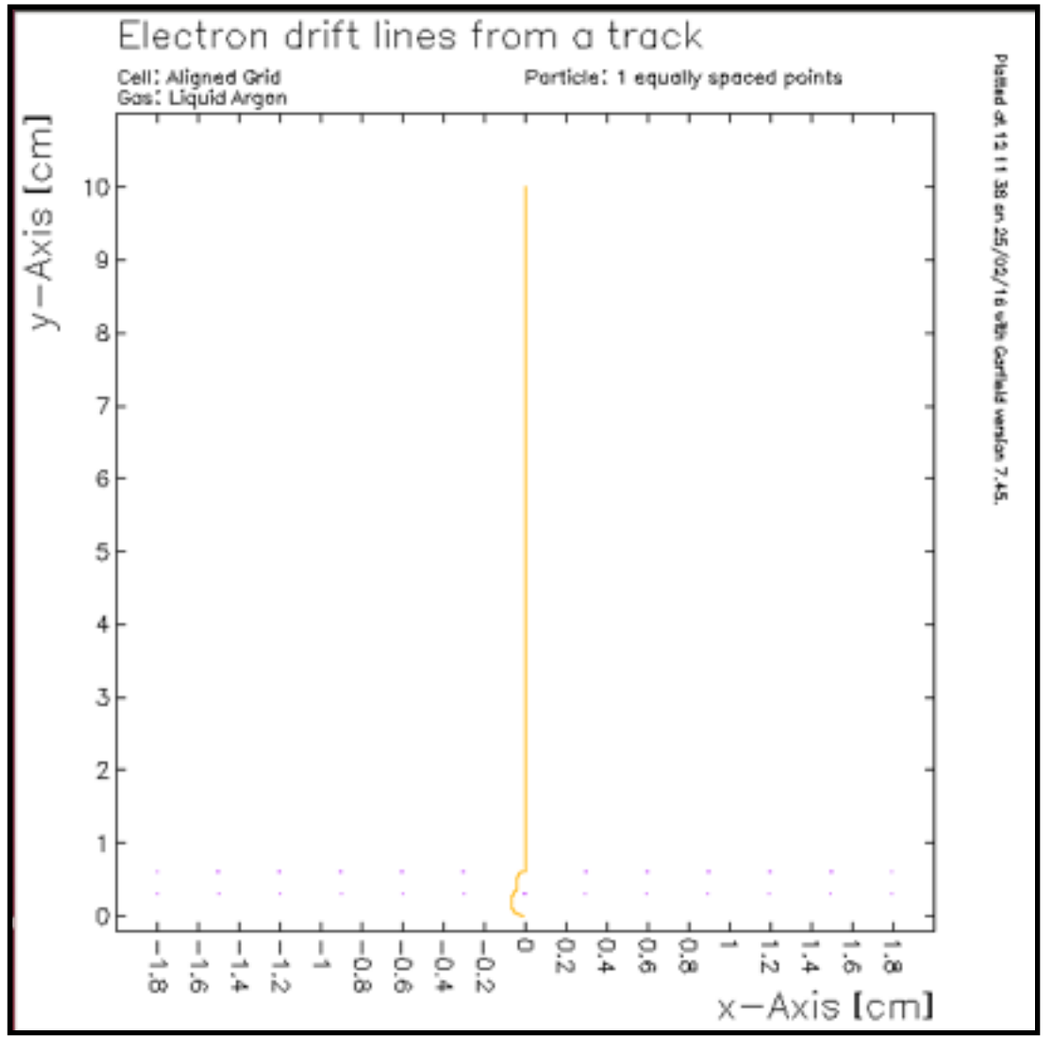
2. We propose to construct a test stand containing a TPC with adjustable wire pitch to perform such a calibration

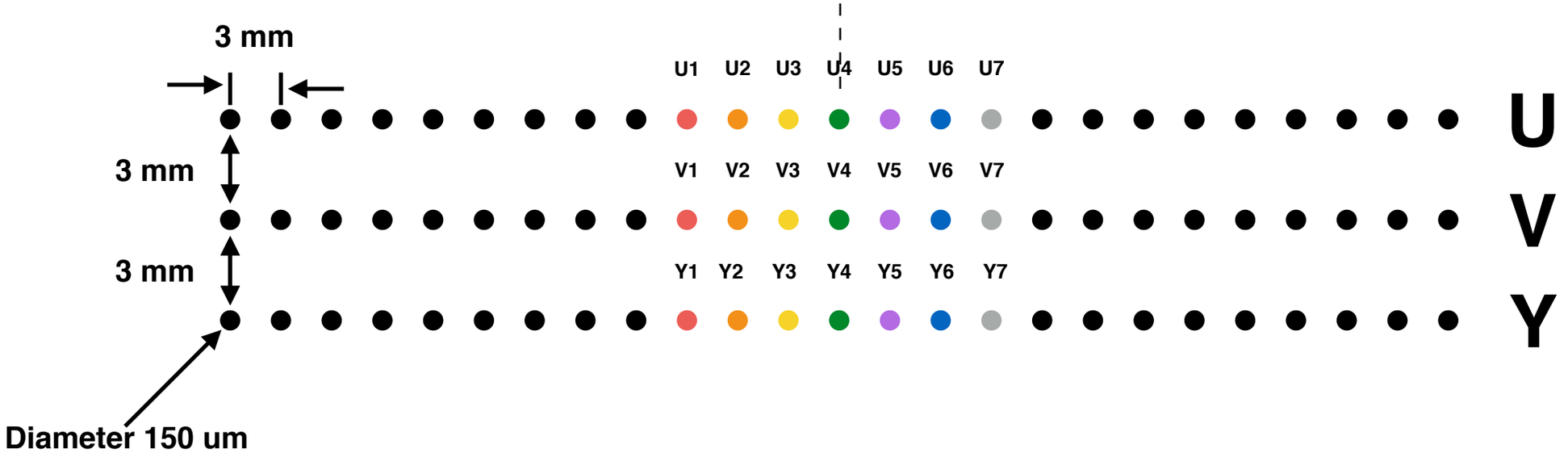
3. At this moment, we should prepare an in-situ calibration device for ProtoDUNE and DUNE

Back up

Current MicroBooNE Field Response

- A single electron is set 10 cm away from the wire plane
- U4, V4, Y4 are the central wires
- Signals are calculated for neighboring wires
- The starting point of the electron is set 0, 0.3, 0.6, 0.9, 1.2, 1.5 mm away horizontally as labelled in on the file name
- Drift field is 0.28 kV/cm





Requirements

- Laser System
  1. 266nm (4.66eV) UV laser with power ~10uJ
  2. Laser distribution system
  3. Fiber system

- Feedthrough for
  1. 10 kV HV connection
  2. Optical feed for laser
  3. Low voltage connection for electronics

- Drift Stack
  1. ~10 cm drift distance
  2. 2-3 guard rings
  3. Cathode plane with gold photocathode integration

- Slow Control for operation
  …

Complications in Field Response Function

- There are difficulties on generating electric field in 3D because the FEA tool cannot meshing properly due the geometry
- Even we finally are able to simulate the field response in 3D, we still need to validate it with measurements